SYNOPSIS

Synthesis and Development of Metal Oxides based Heterojunction Photo-detector and its Applications

Submitting to

Research & Recognition committee (RRC)

Subject: Physics

Under

Faculty of Science and Technology

by

Ms. Asma Begum Ubaidur Rahman
Ph.D. student
School of Physical Sciences
SRTMUN

Under the guidance of

Dr. K. A. Bogle
School of Physical Science
SRTMUN

Title:

Synthesis and Development of Metal Oxides based Heterojunction Photo-detector and its Applications

1. Introduction:

The development of semiconductor thin films for the fabrication of heterojunction devices has covered a wide range of applications including photodetectors, displays, solar cells, optical logic gates, light-emitting diodes (LEDs), optical-image sensors, etc [1,2]

In case of thin film, due to its thickness confinement strong interlayer quantum confinement effect contributes to the extraordinary optoelectronic performance of the corresponding fabricated heterojunction devices. Moreover, their thin nature and strong in plane covalent bonding makes it inherently flexible. This characteristic makes it highly suitable, as active channel materials, for applications in heterojunction electronics and optoelectronics [6-8] devices.

Among all semiconductor materials, metal oxides play very important role in chemistry, physics and materials science. As the metal elements can form a large diversity of oxide compounds and can acquire various structural geometries (1D / 2D / 3D). Metal oxide can show unique electronic properties depending on its shape, size and doping concentration. In technological applications, metal oxide thin films with thickness ranging from several nanometers up to several micrometers are utilized in the fabrication of microelectronic circuits, sensors, piezoelectric devices, fuel cells, coatings for the passivation of surfaces against corrosion, catalysts, etc.

Synthesis of thin film metal oxide nanostructure material has been demonstrated via different techniques included in Wet Chemical, Physical Vapour Deposition (PVD) and Chemical Vapour Deposition (CVD) techniques. Each methodology has associated with its pros and cons and careful consideration of the resulting film properties such as crystallinity, microstructure and adhesion must be taken into account before its viable use in device technology.

2. Review of Literature and Development in the Subject:

UVand IR radiations emitted by the Sun arrive at the earth's surface via the atmosphere, where many complicated absorption and scattering processes happen. This UV radiation is classified as UV-A (400-315 nm), UV-B (315-280 nm), and UV-C (280-100 nm). Among these, UV-A radiation gets absorbed by atmospheric gases and most harmful UV-C radiation gets absorbed by atmospheric oxygen and ozone[1][2]. Most of these UV radiations are harmful to humans as well as living organisms as the ability of UV radiation to penetrate human tissue or cells is directly proportional to its wavelength. UV-A penetrates deep below the skin and causes skin damage and cataract formation. UV-B cause erythema (sunburn) and corneal burn. This painful injury can cause

permanent eye damage and vision loss[3][4]. The UV-B erythema threshold is 1,000 times lower than the erythema threshold of the UV-A, and it is much more effective in causing damage to living tissue than UV-A[5]. UV-C cannot penetrate the dead layer of human skin; however, it can produce a corneal burn. UV-C kills bacteria and it is used in germicidal lamps. Moreover, both UV-A and UV-B rays are important to human health, that is, small amounts of UV rays are essential for the production of vitamin D. Ultraviolet radiation not only affects humans but wildlife as well.[6][7]

On the other hand, infrared (IR) rays also affect the environment, medical studies indicate that prolonged IR exposure can lead to lens, cornea, and retina damage, including cataracts, corneal ulcers, and retinal burns.[8]So we are very thoughtful about the effect of these three UV rays and IR rays on the ecosystem. If UV and IR sensors can be mounted on a small electrical system like a cell phone, we can monitor the dose of UV rays[9]. People made monolayer semiconductor photodetectors and homojunction photodetectors to detect these radiations. The homo junction photodetectors used in the earlier days have higher noise and large leakage currents. This problem can be reduced by using heterojunction photodetectors that have different band gap energies[10]. The heterojunction photodetector has several advantages over the homojunction photodetector and monolayer photodetectors such as high flexibility in band gap engineering and wide availability of various materials and combinations in designing photodetector with better absorption and efficiency[11]. We can detect a high percentage of radiation to prevent our environment[8]. So the skillful integration of photo detective material in this work demonstrated an elegant and universal method to fabricate new types of photodetectors and might inspire more creative work.[8]

Recent literature survey show large number of research reports in the field of metal oxide thin film fabricated on hard substrates for application including solar cells, thin film transistors, sensors, resistive switching devices, ferroelectric memories, etc.

National status:

A number of important research outcomes addressing a variety of issues in this field are supported and many are in progress in various National laboratories and universities in the country funded by Government of India. Although it is difficult to summarize the whole effort, a representative cross section of ideas and strategies can be provided as follows: Dr. S. B. Ogale, NM kaawash, etc. The examples are Sohail Abbasa, et.al. has investigated the all-metal oxide-based photodetector. Satishchandra B Ogale, et.al. has fabricated the heterostructures based oxide thin films Suttinart Noothongkaew et.al. has developed the CuO/ZnO based UV photodetector. Ahmed Obaid M. Alzahraniet.al, has studied the effect of ZnO layer thickness upon optoelectrical properties of NiO/ZnO heterojunction prepared at room temperature. Jose, J. et.al. has written a review on the ZnO heterojunction photodetector for UV application. Govinda Lakhotia, has

investigated the TiO_2-ZnO based thick film 'Solar Blind', Photo-Conductor for Green Electronics.

International status:

Many researchers across the globe are working to enhance the performance of photodetctors. The international research is just beginning to grow creating an open opportunities for Indian science to take a lead and make a substantial impact. These developments are occurring in the domains of new device concepts. Lots of literature is available on various reputed research journals like: Advanced Materials, Nano Letters, Advanced Functional Materials, etc. Few impressive examples who flourish the focus of this project are: Soci C. et.al. has investigate the ZnO nanowire UV photodetectors with high internal gain. Fu X.Q. et.al. has evaluate the Anomalous photoconductivity of CeO2 nanowire in air. Xue X.Y. et.al. has investigate the Individual core-shell structured ZnSnO3 nanowires as photoconductors. Kuang Q. et.al. has deliberate the Enhancing the photo-and gas-sensing properties of a single SnO_2 nanowire based nanodevice by nanoparticle surface functionalization. Sakai N. et.al. has utilized the Manganese Oxide nanosheets for visible light detection. Siya Huang et.al, has fabricated n-SnO2 nanobelts-p-NiO heterojunctions ultraviolet photodetector. N.P. Klochko has investigated the NiO/ZnO based heterojunction UV photodetctor.

3. Objectives of Research/proposed Hypothesis

This work investigates the photoconducting properties of metal oxide thin films synthesized using spray pyrolysis technique on glass substrates and possible development of highly sensitive and responsive optoelectronic device using the deposited film.

To achieve the above mention objective this work aims;

a. To synthesize metal oxide thin film on glass substrate using spray pyrolysis technique.
b. Characterize these thin films using XRD, UV-Vis spectroscopy, Raman spectroscopy, SEM, EDS, XPS, etc.
c. To investigate the photoconducting properties of metal oxide thin film samples using dedicated optoelectronic characterization setup. This includes responsivity, detectivity, response (rise/decay) time, sensitivity, gain, etc.
d. To deposit heterostructured thin films and investigate the photoconducting properties of heterostructure device using dedicated optoelectronic characterization setup
e. To develop a prototype effective heterojunction photodetector device based on the results and material properties.

4. Methodology to be adopted

This work includes synthesis of metal oxide materials for its viable application in development of optoelectronic device application. This work designed to run on three stages;

Stage-1: Fabrication of thin films of metal oxide:

The motivation behind this stage is to investigate the growth and physical properties of amorphous and polycrystalline metal oxide films grown on glass substrate. Individual goals of this stage are.

a. Synthesis of high quality metal oxide thin films on glass substrates via spray pyrolysis techniques.
b. Characterization of thin films using XRD, TGA, UV-Vis spectroscopy, Photoluminescence spectroscopy, SEM, and AFM etc.
c. Investigation of photo conducting properties of metal oxide thin films with respect to their thickness, dopant concentration, and electrode gap.

Stage 2: Establish the electronic structure of the films and correlate with its photoconducting property:

a. Investigation of the electronic structure of the metal oxide thin film using X-ray photoelectron spectroscopy.
b. Correlating the role of deposition parameters, dopant concentration and film thickness with the observed photoconducting properties.

Stage 3: Development of heterojunction optoelectronic device based on the obtained results:

The glass substrate used in this work must be optically inert.

a. Investigation of photo conducting properties of metal oxide thin film on glass substrates.
b. Use of the above investigated properties of the dopant for determination of viable optoelectronic material based on metal oxide thin film.

During the final stage of the work, efforts will be made to fabricate and demonstrate metal oxide thin film based heterojunction optoelectronic device for its viable application in current semiconductor market

5. Importance of study/ Society application:

National status:

Vital research outcomes talking a variety of issues in this field are supported and many are in progress in various National laboratories and universities in the country funded by Government of India. Although it is difficult to summarize the whole effort, a representative cross section of ideas and strategies can be provided as follows: Dr. S. B. Ogale, , Dr. Abhimanyu Rana, Dr. Rajesh Hyam, Dr. S. S. Islam, Dr. S. H. Husale, Dr. Navneet Agrawal, Dr. K. S. Narayan, Dr. Soumyajit Roy etc.

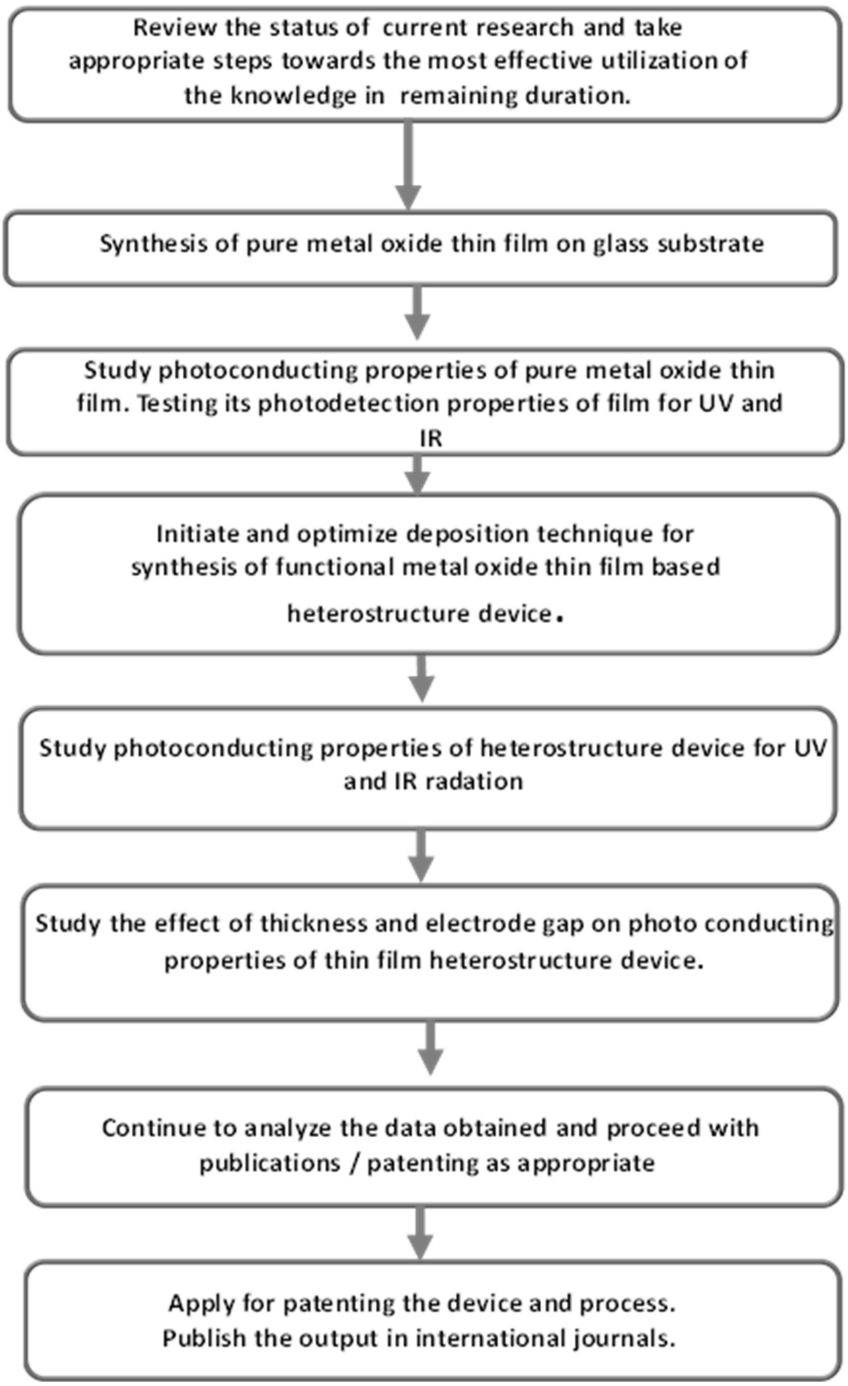
International status:

Heterostructure photodetector device technologies over the past decades has given us devices with powerful capabilities due to advance materials and many researchers across the globe are working to enhance the performance of flexible PDs. International research is just beginning to grow creating an open opportunities for Indian science to take a lead and make a substantial impact. These developments are occurring in the domains of new

device concepts. Few impressive examples who flourish the focus of this project are: Dr. Joondong Kim, Dr. S. Sawyer, Dr. Guowei Yang, Dr. U. Jeong, Dr. Z. L. Wang, Dr. Y. A. Zhang, Dr. H. J. Kim, etc. Lots of literature is available on various reputed research journals

6. Proposed work Plan/ Formulation and Structure of Study: Year-wise Plan of work and targets to be achieved

Outline of Plan of work:


Review the status of current research and take appropriate steps towards the most effective utilization of the knowledge in remaining duration.
Synthesis of pure metal oxide thin film on glass substrate
Study photoconducting properties of pure metal oxide thin film. Testing its photodetection properties of film for UV and IR
Initiate and optimize deposition technique for synthesis of functional metal oxide thin film based heterostructure device.
Study photoconducting properties of heterostructure device for UV and IR radation
Study the effect of thickness and electrode gap on photo conducting properties of thin film heterostructure device.
Continue to analyze the data obtained and proceed with publications / patenting as appropriate
Apply for patenting the device and process.
Publish the output in international journals.

5. Work plan (Year wise):

The studies those will be undertaken through this project, will be carried out in the various successive stages as below. The milestones and duration would be as under:

Year	Work plan
First Year	• Synthesis of pure metal oxide thin film on hard substrate and optimize thin film growth methods (spin coating / spray pyrolysis) • Structural/chemical/optical/morphological characterization of metal oxide thin films. • Testing its photo conducting properties.
Second Year	• Initiate and optimize deposition technique for synthesis of heterostructure device and characterize them. • Structural/chemical/optical/morphological characterization of metal oxide thin films. • Testing its photodetection properties.
Third Year	• Study the effect of thickness on photo conducting properties of thin film heterostructure device. • Perform extensive characterization to study the interface. • Testing of photoconducting properties of it.
Fourth Year	• Initiate the first step to develop a prototype photodetector device based on the results obtained. • Testing the device under various conditions like temperature, humidity, radiation exposure, etc.
Fifth Year	• Review the status of progress • Apply for patenting the device and process. • Publish the output in international journals. • Finding industrial collaborator.

References

1. Ogale, S.B. ed., 2006. Thin films and heterostructures for oxide electronics. Springer Science & Business Media.
2. Sohail Abbas, et.al. "All metal oxide-based transparent and flexible photodetector" Materials Science in Semiconductor Processing, 2018, 88, 86-92.
3. Kaawash, N.M., Kejriwal, N., Halge, D.I., Narwade, V.N., Rana, A.S., Dadge, J.W., Jejurikar, S.M., Alegaonkar, P.S. and Bogle, K.A., 2022. Highly stable and sensitive photon detection performance of ZnO thin film for ultraviolet light. Physica B: Condensed Matter, p.413905.

4. Alzahrani, A.O.M., Abdel-wahab, M.S., Alayash, M. and Aida, M.S., 2018. Effect of ZnO layer thickness upon optoelectrical properties of NiO/ZnO heterojunction prepared at room temperature. Journal of Materials Science: Materials in Electronics, 29(19), pp.16317-16324.
5. Jose, J., Ravindran, A. and Nair, K.K., 2017. A review on ZnOheterojunctionphotodetector for UV application. Ictact J. Microelectronics, 2, pp.305-310.
6. GovindaLakhotia, "An Investigation on TiO2-ZnO based Thick Film 'Solar Blind', Photo-Conductor for 'Green' Electronics", Materials Science and Engineering: B, Vol. 168, No. 1-3, pp. 66-70, 2010.
7. Shashikant Sharma and C. Periasamy, "Simulation Study and Performance Analysis of n-ZnO/p-Si HeterojunctionPhotodetector", Journal of Electron Devices, Vol. 19, pp. 1633-1636, 2014.
8. Soci C., Zhang A., Xiang B., Dayeh S.A., Aplin D.P.R., Park J., Bao X.Y., Lo Y.H., Wang D. ZnO nanowire UV photodetectors with high internal gain. Nano Lett. 2007; 7:1003–1009.
9. Fu X.Q., Wang C., Feng P., Wang T.H. Anomalous photoconductivity of CeO2 nanowire in air. Appl. Phys. Lett. 2007; 91:073104:1–073104:3.
10. Xue X.Y., Guo T.L., Lin Z.X., Wang T.H. Individual core-shell structured ZnSnO3 nanowires as photoconductors. Mater. Lett. 2008;62:1356–1358.
11. Kuang Q., Lao C.S., Li Z., Liu Y.Z., Xie Z.X., Zheng L.S., Wang Z.L. Enhancing the photo-and gas-sensing properties of a single SnO2 nanowire based nanodevice by nanoparticle surface functionalization. J. Phys. Chem. C. 2008;112:11539–11544.
12. Sakai N., Ebina Y., Takada K., Sasaki T. Photocurrent generation from semiconducting Manganese Oxide nanosheets in response to visible light. J. Phys. Chem. B. 2005;109:9651–9655.
13. Huang, S., Wu, H., Matsubara, K., Cheng, J. and Pan, W., 2014. Facile assembly of n-SnO 2 nanobelts–p-NiOheterojunctions with enhanced ultraviolet photoresponse. Chemical Communications, 50(22), pp.2847-2850.
14. Feng P., Zhang J.Y., Wan Q., Wang T.H. Photocurrent characteristics of individual ZnGa2O4 nanowires. J. Appl. Phys. 2007;102:074309:1–074309:5.
15. Klochko, N.P., Kopach, V.R., Tyukhov, I.I., Zhadan, D.O., Klepikova, K.S., Khrypunov, G.S., Petrushenko, S.I., Lyubov, V.M., Kirichenko, M.V., Dukarov, S.V. and Khrypunova, A.L., 2018. Metal oxide heterojunction (NiO/ZnO) prepared by low temperature solution growth for UV-photodetector and semi-transparent solar cell. Solar Energy, 164, pp.149-159.
16. Meng Ding, Dongxu Zhao, Bin Yao, Zhipeng Lid and XijinXu, "Ultraviolet Photodetector based on Heterojunction of n-ZnOMicrowire/p-GaN Film", RSC Advances, Vol. 5, No. 2, pp. 908-912, 2015.

Signature
Research Scholar

Signature
Research Supervisor
(Guide)